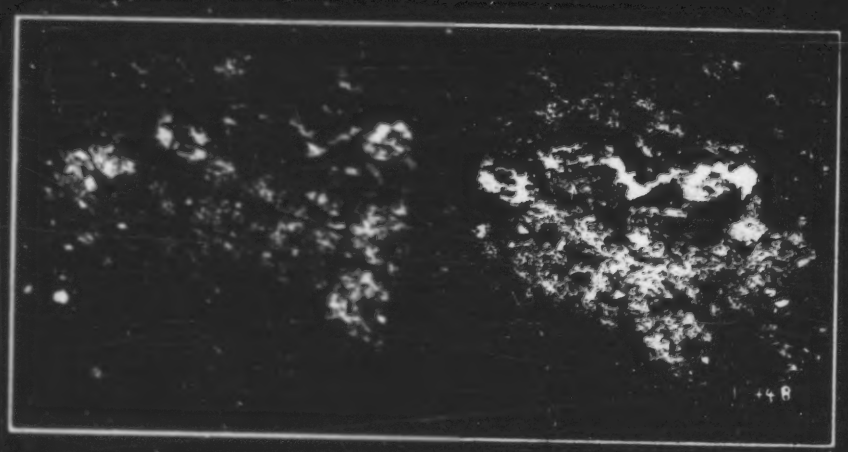
Use of large-scale aerial photographs in regeneration assessments



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One of six regional research centers, two national forestry institutes, and a headquarters unit, NoFRC is located in Edmonton, Alberta, and has suboffices in Prince Albert, Saskatchewan, and Winnipeg, Manitoba. Until joining Agriculture Canada in 1984 under a Minister of State for Forestry, the Canadian Forestry Service was part of Environment Canada.

Cover photo: 1:580 color stereopair with 5 × 5 sampling grid overlay representing a single plot cluster of 250 m² total area: photo stocking 72%, ground stocking 76%.

USE OF LARGE-SCALE AERIAL PHOTOGRAPHS IN REGENERATION ASSESSMENTS

R.J. Hall

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ABSTRACT

The major considerations for use of large-scale aerial photographs in regeneration assessments are presented. The boom (fixed-base) and Northern Forest Research Centre (sequential) camera systems are compared to provide the potential user with fundamental knowledge of the differences between them. The most important factors governing the selection of a camera system are system availability and intended applications. Survey design methodology is briefly discussed in relation to large-scale photo sampling. Indications of large-scale photo capabilities are described using the results of a reconnaissance survey conducted in 1980 in Manitoba.

RESUME

On présente les principaux critères de l'utilisation de photographies aériennes à grande échelle pour les évaluations de la régénération. On compare les chambres à support fixe et celle à défilement du Centre de recherche forestière du Nord, pour informer l'utilisateur potentiel sur les moyens de les distinguer rapidement. Les principaux facteurs de sélection d'une chambre photographique sont son accessibilité et l'utilisation qu'on entend en faire. Les méthodes d'établissement d'un plan d'échantillonnage en vue de la photographie à grande échelle sont brièvement traitées. Les possibilitiés de la photographie à grande échelle sont décrites par les résultats d'un relevé de reconnaissance réalisé en 1980 au Manitoba.

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NOTE

The exclusion of certain manufactured products does not necessarily imply disapproval nor does the mention of other products imply endorsement by the Canadian Forestry Service.

INTRODUCTION

Recent and increased activity in regeneration silviculture (Canadian Forestry Service 1981, 1982) has encouraged investigative work into the application of large-scale photography (LSP) for regeneration assessments. This statement is supported when considering the current inadequacy of reforestation in Canada, and the continual growth of nonsatisfactorily restocked (NSR) backlog areas (Brace and Golec 1982). Potential applications of LSP include assessment of forest stocking and silvicultural treatments and the monitoring of stand establishment.

At the Northern Forest Research Centre, the purpose of the large-scale photo program is the cooperative research and development of new applications utilizing as much as possible current technology and hardware, the refining of existing techniques, and in technology transfer. Projects undertaken are to support, not compete with systems that may be in use by the private sector. The direction of the LSP program is therefore toward assisting public agencies and private companies in further developing their ability to use LSP as a tool for meeting their information needs.

The application of LSP to regeneration assessments requires consideration of many complex technical factors, including geographic location and the information required. The first objective of this report is to present in simplified form the major considerations of which a user should be aware. Some technical aspects and comparisons of camera systems for acquiring LSP are presented. Sampling design considerations in the context of LSP are discussed to provide an appreciation of its significance and role. The second objective of this report is to summarize results from a cooperative reconnaissance study with Abitibi-Price Inc. in Pine Falls, Manitoba, in order to illustrate application of the above information. The capabilities of large-scale photography were evaluated at three scales.

Role of large-scale photography

A number of research trials (Ball and Kolabinski 1979; Kirby 1980; Butler 1983) have involved assessment of forest stocking using the stocked quadrat technique and group-plot surveys. The greatest potential role of LSP is generally in augmenting rather than in replacing ground regeneration surveys, though the role will vary with region and application. For example, ground surveys may not necessarily be needed for logged-over areas that are greater than 10 years old and have yet to be surveyed (backlog). Trials are being undertaken in Newfoundland to determine the potential of incorporating LSP into the overall regeneration survey strategy (Butler 1983). In Alberta, however, the problem of dense shrub and grass and the rigid provincial requirements for regeneration surveys focus the greatest role of LSP to reducing the total area requiring ground surveys. By identifying those areas that are clearly stocked or not sufficiently restocked (NSR), the regeneration survey program is made more efficient. There is great potential in applying LSP to stand dynamics because there is little information on regenerating stands following harvesting to stand establishment (Bella and De Franceschi 1978). Cooperative reconnaissance studies have been conducted in the Yukon with the Pacific Forest Research Centre and in Manitoba with Abitibi-Price Inc.

An advantage of large-scale photo sampling is that most of the regeneration assessment work can be done at any time in the office under comfortable conditions. This could be of particular value because time during the field season is usually needed for other purposes. Survey results can also be easily checked by other interpreters. In addition, the photo approach to sampling can be flexible to accommodate different sampling intensity levels, and surveys of inaccessible areas are possible. Another advantage of LSP is that a permanent record of sample plots is obtained. This provides the opportunity for future work to be done on the plots (such as obtaining stocking information first and obtaining detailed information on site and seedling distributions, height, competition, etc. at a later date).

TECHNICAL CONSIDERATIONS

The following sections provide practical base information regarding the application of large-scale photography to regeneration assessments. It is intended as a general checklist or guide rather than as a manual, which would necessarily be user-specific.

The entire process from project initiation to photo acquisition and mensuration is briefly discussed. In addition, the two major camera system approaches, the fixed-base camera boom system and the two-camera sequential system, are briefly contrasted.

Project objectives

The most important decision in planning a survey project is a clear definition of the information required. All project specifications and procedures can be developed once the requirement is clearly identified. Different levels of information are required for different purposes. A flow chart is a useful tool in the production of a user's guide for regeneration assessments. The flow chart assists project design to identify procedures for surveys that meet user needs, costs, and constraints. Using the same concept, Maxim and Harrington (1983) discussed a hierarchical structure to identify aerial survey design alternatives that can be applied to the survey at hand. Procedures can therefore be developed upon identification of user needs (stand maps, stocking estimates by stratum, regeneration seedling heights, regeneration density).

Flight preparation and specifications

The magnitude of work required by the user is dependent on whether the photography will be acquired in-house, or by a contractor. Flight preparation and acquisition procedures are much more extensive when a user acquires his own photography. The logistics of aircraft availability, camera system and maintenance, flight plan design, computations, and actual operation must be considered. The advantage of acquiring one's own photography is that there is direct control over how and when the photo mission is conducted; the disadvantages are that capital costs and personnel resource requirements are greater. Failure in an operation may also mean repeated absorption of costs by the user rather than by a contractor. Photo acquisition by a contractor would alleviate much of the work and responsibility in the flight plan design but would require close evaluation of the final products before payment. The user must be aware that time frame and project size considerations will govern which approach will be preferable. Combinations of in-house and contract strategies are therefore often applicable. For example, the photo acquisition may be contracted with photo interpretation being done in-house.

Both approaches require knowledge of the major variables involved in air photo acquisition. Beyond the variables discussed below, the reader may wish to refer to the 1982 Specification for Aerial Survey Photography by the Interdepartmental Committees on Air Surveys, Goba et al. (1982), and Wolf (1974).

Cameras, aircraft, and scale

Considerations for cameras include type and format, shutter speed range, aperture range, and available lenses. The types of cameras to be employed will, in part, govern the selection of the aircraft. For example, very large photo scales require low altitudes and slow aircraft speeds, which may preclude use of fixed-wing aircraft. The three different types of cameras that are available are in 35-, 70-, and 240-mm formats. The advantages and disadvantages for selection of camera systems are presented later.

Fixed-wing aircraft are particularly suited to operations requiring smaller scales (<1:800) and where the cameras are mounted internally. Easy access to cameras permits rapid changes of film magazines and provides for more economical operations. Mounting of cameras externally on fixed-wing aircraft is not generally recommended as frequent landing to change film magazines would increase total flight time and cost. This would be particularly true in northern regions where there are few landing strips. A range of scales from 1:200 to 1:500 or smaller can be acquired using rotary-wing aircraft. Visibility, low-speed flight capability to limit image motion, and the ability to land in various locations make the helicopter well-suited for low-level flights.

Photo scales required are determined by the information requirements. Scales at 1:5000 to 1:10 000 are, for example, useful for aerial stratification. Larger scales of 1:250-1:500 can be used for density or stocking estimates in a statistical sampling framework.

Regardless of the camera system used, computations are needed to determine camera cycling intervals, image motion, and film consumption. Once these are calculated, adjustments from the desired flight plan are sometimes needed to produce an efficient design. To assist in this process, a microcomputer program has been written at NoFRC for its camera system to calculate the parameters by entering data through a series of user prompts.

Film, exposure, and processing

There are three types of aerial film that are most useful for regeneration assessments: Kodak aerocolor negative 2445, Kodak Ektachrome MS aerographic 2448, and Kokak Aerochrome Infrared 2443. The reversal film produces a positive transparency that is suitable for office interpretation but not for field use (though prints can be produced for the field). Two important characteristics of aerial film are exposure latitude and effective aerial film speed. Simply stated, films with wide exposure latitudes can accommodate more variable conditions and still produce a reasonably well-exposed photograph in comparison to films with narrow exposure latitudes. Aerial reversal films have

narrow exposure latitudes that make the setting of aperture and shutter speed more critical. Kodak 2445 is more flexible in this regard. Available lighting must also be greater for aerial reversal films because their film speeds are slower. Beyond these considerations, aerial photography is not necessarily limited to use of aerial films. Other films may be substituted if they are suitable for the application and can be obtained in the type and form required for the cameras to be used. The amounts of films to purchase may depend on considerations of handling and storage. Color aerial films in 70-mm format, for example, must often be purchased in minimum lots of 24 rolls.

The determination of film exposure requires consideration of film speed, sun angle, geographic latitude and longitude, and time of day and year. The shutter speed and aperture range of the camera must also be considered. Useful aids to determine exposure are a sun angle computer program written at NoFRC and the Kodak Aerial Exposure Computer. Incorporation of a photometer into the camera system, as done by the Ontario Centre for Remote Sensing, provides the best aid for determining exposure.

Processing and printing of aerial films are generally done at the Reproduction Centre of the National Air Photo Library in Ottawa, Ontario. The turnaround time is generally 3-4 weeks plus transport time. The advantage of using nonaerial films is that processing can generally be done locally, thereby reducing turnaround time.

Timing

Timing for procuring photography is critical and best during spring or fall (Kirby 1980). Photography in the spring should be after snowmelt but prior to hardwood leaf-out and green-up of shrubs, grasses, and herbs. Photography in the fall should be after browning of ground vegetation. Summer photography is not recommended because ground vegetation or trees in foliage often obscure regenerating seedlings. From an operational viewpoint, photography during spring with the fall as a backup time will maximize the probability of obtaining the necessary photographs during a single year. In addition, spring photography provides the opportunity for fieldwork with the photos during the summer or fall followed by photo interpretation during the winter.

Camera systems

Large-scale photography can basically be acquired in two ways; timed interval sequential photography with a single camera and a two-camera fixed-base system (e.g., the boom system employed by the B.C. Ministry of Forests). Of the different types of cameras available, the 70-mm format is most popular for LSP.

The large capital outlay required for a camera system generally makes such an acquisition economical only through cost amortization in the long term. The short-term view has been to contract work out to private companies that can provide LSP services. At present, only the fore-and-aft fixed-base camera boom system is commercially available for purchase. The acquisition of any other system would require supervision of piecemeal contracts to assemble the components to produce the system that can be used for the desired applications. The sequential camera systems are currently not commercially available, though individual components can be purchased separately (e.g., cameras, intervalometer, altimeter).

Contracting for LSP services may include photo acquisition or interpretation and mensuration, or both. Complete services can be provided by Hunter and Associates and Timberline, who each have a boom system, and by Dendron Resource Surveys Ltd., who have a sequential Vinten 70-mm system in a fixed-wing aircraft. A wing-tip Vinten camera system is also available for LSP acquisition by Selkirk Remote Sensing Ltd. (Selkirk). The NoFRC system is a 2 Vinten 70-mm camera sequential system that is used in cooperative research and development projects.

When operated in fixed-wing aircraft, 240-mm cameras are not well-suited to very large-scale photography because of cycling rate, image motion, and out-of-focus considerations. Nevertheless, 1:1000 scale photographs are technically possible when taken with a 300-mm lens at slow aircraft speeds. Large-format cameras are better suited for smaller scales to provide overviews for stratification and planning purposes. The manual by Goba et al. (1982) merits consideration for application at this level.

Boom system

The boom camera system consists of two Hasselblad Mk 70 cameras mounted 6.1 m apart on a boom 7.2 m long (Bradatsch 1980) (Fig. 1). The system is Ministry of Transport tested and approved for installation onto Bell 206-B and Bell 206-L1 helicopters. Stereopairs are acquired simultaneously by operator or by timed intervals. The advantages of fixed-base over sequential photography are that errors due to differential tip-and-tilt are minimized and that flying height does not vary significantly for the stereopair (Rhody 1977). In

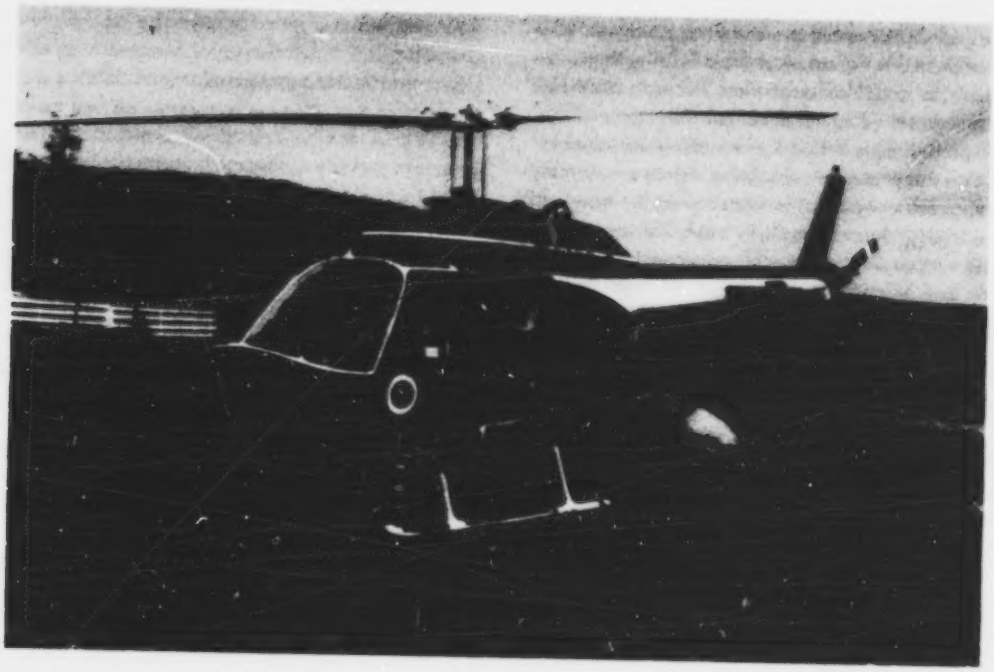

Figure 1. Boom system mounted under a Bell 206B helicopter. Source: Hunter and Associates, Mississauga, Ontario.

Figure 2. NoFRC camera system mounted under a Bell 206B helicopter.

addition, the basis for a rigid photogrammetric model is that there are parallel camera axes. To adjust for systematic error that may occur, Hunter and Associates employs calibration procedures to develop correction factors for camera alignment[1]. Williams (1978) commented on the difficulties in making both cameras fire simultaneously using fore-and-aft fixed-base cameras. He noted that with small base-to-height (B/H) ratios[2], small uncertainties in B can amplify into large uncertainties in the vertical or Z scale of the model. Spencer (1979) used twin 70-mm Vinten cameras mounted on a 4.9-mm (16-foot) boom oriented parallel to the direction of flight. Imprecise synchronization was determined to cause inaccuracies in estimates for flying height. Regression improved the accuracy of estimated values but not as much as did application to the boom mounted transverse to the flight. In recognition of this problem Hunter and Associates has designed a synchronization monitor that monitors flight delays of up to 5 milliseconds due to variations in flight. A brief technical comparison between the boom and NoFRC camera systems is given in another section.

NoFRC system

The NoFRC camera system is composed of two 70-mm Vinten aerial cameras, a Honeywell radar altimeter, and a black-and-white video camera housed in a pod built by Didec R. and D. Ltd.[3] The pod is externally mounted under a Bell 206B jet ranger helicopter (Fig. 2). In addition, an instrumentation rack also built by Didec R. and D. Ltd. is mounted in the rear cabin of the Bell 206B (Fig. 3). The analogue radar height indicator, mechanical intervalometer (Van Eck and Bihuniak 1978), batteries, and video monitor and recorder are mounted on the rack. Both the rack and pod are Ministry of Transport tested and approved for Bell 206B and Cessna 185 aircraft. Lenses of different focal lengths are mounted on the cameras. The cameras are fired sequentially, resulting in simultaneous localized and broader views of the terrain. With two cameras, the system is therefore capable of acquiring two scales of photography using different films. This is particularly useful for tracking purposes, because the film format results in small areas being photographed at large scales. The altimeter performs within the manufacturer's accuracy standard of ± 4%, and calibration is generally recommended as an operational procedure (Kirby and Hall 1980).

Comparing the boom and NoFRC camera systems

Considerable interest has been generated in the selection of a 70-mm format camera system for acquiring LSP. The choice is basically between the sequential system and the boom system. It appears that only Dendron Resource Surveys Ltd. and NoFRC have sequential systems in Canada.

In regeneration assessments, the intended use of the photography at specified scales will greatly influence the suitability of a particular camera system. Either system is suitable for stocking assessments at ultralarge scales. The measurement of seedling heights is sometimes of interest to silviculturists. The accuracy of height determination is greatly dependent upon the B/H ratio of the stereoscopic pair (American Society of Photogrammetry 1980). The percentage overlap between the stereopair and the vertical exaggeration[4] are also influenced by the B/H ratio. Smaller B/H ratios with greater overlap result in less vertical exaggeration and reduced accuracy in measurements and in detection of seedlings. To provide a basis of comparison, the following formula was used to calculate theoretical measurement precision error (American Society of Photogrammetry 1980):

$$\Delta h = \frac{H}{f}\,\frac{H}{B}\,\Delta Px$$

where Δh = measurement error
H = height above ground
f = camera lens focal length
B = airbase
ΔPx = measurement parallax (0.03 mm)

Using the NoFRC system as an example of a sequential camera system, measurement precision errors were contrasted with the boom systems (Table 1). These measurement precision figures have a relationship with stocking assessments in relation to the measurement of detectable seedlings discussed in the Manitoba reconnaissance study results. A characteristic of the boom system is the lack of control of the B/H ratio due to the fixed separation between cameras. Measurement

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[1]Personal communications from Hunter and Associates,6870 Goreway Dr., Suite 201, Mississauga, Ontario, L4V 1P1. August 1983.
[2]B/H ratio is the ratio of airbase and flight height of a stereoscopic pair of photographs (American Society of Photogrammetry 1980).
[3]17th Ave., R.R. 2, Markham, Ontario, L3P 3J3.
[4]The increase or decrease in the vertical dimension of the perceived stereomodel when compared to its horizontal dimension ratio of the actual object (American Society of Photogrammetry 1980).

Figure 3. Instrumentation rack mounted in rear cabin of Bell 206B helicopter.

Table 1. Comparison of base-to-height (B/H) ratios and measurement precisions for three scales.

	Boom			NoFRC					
	1:250	1:500	1:1500[a]	1:250	1:500	1:1500	1:250	1:500	1:1500
Focal length (mm)	100	100	100	152.9	152.9	152.9	281.9	281.9	281.9
Height AGL[b] (m)	25	50	150	38.2	76.5	229.4	70.5	141	422.9
Overlap (%)	53.7	78.6	92.9	70	70	70	70	70	70
B/H	1/4	1/8.2	1/24.6	1/8.9	1/8.9	1/8.9	1/16.4	1/16.4	1/16.4
Measurement precision (m) ±	0.03	0.12	1.1	0.07	0.13	0.40	0.12	0.25	0.74

[a] Considered to be upper limit of boom system for simultaneous stereopairs (Personal communication with Hunter and Associates, 1982).
[b] AGL: above ground level.

precision is therefore best at ultralarge scales. The NoFRC system is more uniform in this regard. Assuming parallel camera axes between exposures, the boom system is more accurate than the NoFRC sequential system at very large scales and less accurate at smaller scales (Table 1). Operational precisions, however, have been found to be better than the figures represented in Table 1[5]. Some of the technical differences between the two systems are presented in Table 2. The smallest scale attainable with the boom system for simultaneous stereopairs is considered to be 1:1500[5]. It is beyond the scope of this report to provide a complete evaluation of the two systems.

Photographing an exact ground location or ground plot location of photo plots can be a difficult exercise. Hunter and Associates uses video tracking, which simplifies this procedure, and ground plots have been located and flagged prior to photography, though this is not necessarily needed. This can also be done with the NoFRC system, but ground location and measurement are generally done after the photography has been acquired.

Both systems are capable of acquiring quality photography. Because the survey design and interpretation procedures are much the same, the choice of system depends on the user, range of intended applications, and system availability.

Photo preparation

Photo preparation involves annotation and documentation. The two main purposes of preparation are to relate the various film scales acquired by numbering roll and film frames, and to facilitate the plotting of flight line locations with other film frames, film scales, and maps. This procedure is especially necessary with photography acquired from small-format cameras. For example, a photograph at a scale of 1:300 would cover approximately 17 m across the frame. It would be difficult to pinpoint the actual geographic location of such a small distance without ancillary information.

Measurement-interpretation systems

Cost and the type of interpretation desired will influence the measurement-interpretation system needed. The simplest and least expensive consists of a calculator and a 4× pocket stereoscope with transparent grids. Optical magnifiers with calibrated scales may also be employed. Parallax bars may be used for measurement of seedling heights. Among the more sophisticated of these is a stereoviewing instrument interfaced to a microcomputer. Two examples are the Zeiss G-2 Stereocord (Fig. 4) and the Carl Zeiss Jena Interpretoscope (Figs. 5 and 6). Interfacing such equipment with software can result in mensuration, data processing, printing, and plotting activities. Descriptions of the Stereocord system are given by Aldred and Lowe (1978) and Hobbie (1976), and a brief description of the Interpretoscope is given by Carl Zeiss Jena (1966) and Kirby (1980). A 3-axis digitizer with encoders incorporated into the Interpretoscope has been completed to facilitate interfacing with microcomputers. Both systems are accurate. A fundamental difference between the two systems is that the region of overlap is viewed by moving the photo carriages on the Stereocord and by moving rotatable handles above the photos on the Interpretoscope. For the latter, the photos are not moved once oriented and mounted on the light table viewing surface.

Survey design

The sampling design is an important aspect of any survey requiring estimates of a given population at a specified precision level within cost limits. Remote sensing considerations (e.g., photo procurement, timing, flight planning) should be integrated with the sampling plan to produce a complete survey design that will ensure user needs are met at a reasonable cost. A useful conceptual guide is presented by Maxim and Harrington (1983) for aerial survey design with statistical sampling options. A sampling design defines such factors as plot selection method, size of sample, and sampling error (Tardiff 1965).

The simplest and most practical approach to a survey design using large-scale photography for regeneration assessments is a systematic consideration of the following factors:

1. sample area stratification;
2. random or systematic sample plot layout;
3. single-stage or two-stage sample design;
4. single plots or group of plots;
5. relationships between photo and ground plots; and
6. sample size.

Survey design criteria should also consider the size of the sampling area or stratum, and the variation of seedling distribution within the stratum. In implementing the framework presented above, there is an important

[5]Personal communication from Hunter and Associates.

Table 2. A comparison of features of the boom and NoFRC camera systems

	Boom[a]	NoFRC
1. Type	Two-camera system for simultaneous stereopairs. Video tracking for broader view of area.	Two-camera system with telephoto and wide angle lens for simultaneous localized and broader views.
2. Photogrammetry	Basis for photogrammetric model because of parallel camera axes with calbration. No differential tip or tilt within the stereopair.	Rapid cycling reduces opportunity for altitude changes between exposures. Tip-and-tilt indicator needed for photogrammetric models.
3. Control	Camera synchronization may not be perfect and is controlled to the 5 millisecond range.	Radar altimeter used for scaling with calibration. Use of laser altimeter would eliminate need for calibration.
4. B/H ratio	B/H ratio changes with altitude, e.g., 1/8 at 1:500 1/16 at 1:1000	Control of B/H ratio by controlling overlap.
5. Film capacity	115 stereopairs for two film magazines.	Bulk loading of film—160 stereo-triplets or 250 stereopairs per loaded film magazine.
6. Location	A video camera with in-flight audio camera monitoring can be used for tracking, and several stereopairs can be taken of critical locations. Ground plots are often flagged before flying.	Use of tracking camera facilitates ground location of photo plots not previously located on the ground.
7. Altitude	Altitude ceiling 150 m unless firing the cameras sequentially at slow speeds.	Ceiling is essentially that of aircraft.
8. Cameras	Hasselblad MK-70 cameras: maximum shutter speed: 1/500 second, maximum cycling rate: 1 per second.	Vinten (models 492 and 518): maximum shutter speed: 1/2000 second, maximum cycling rate: 6 per second.
9. Image motion	Flying at slow speeds to minimize motion due to low maximum shutter speed of Hasselblad relative to the Vinten.	Faster cycling permits flying at faster speeds.
10. Batteries	Battery charge levels must be carefully monitored. Complete set of back-up is recommended. Batteries located in boom and subject to cool temperatures.	Gel/cells in cabin of aircraft, though greater storage or use of aircraft power would be preferable.

[a] Some information provided by Hunter and Associates.

Figure 4. Sterocord interpretation system with Direc-1 interface and central unit and HP 9825 microcomputer and printer. Source: R. Nesby, Resource Inventory Section, Resource Evaluation and Planning Branch, Alberta Energy and Natural Resources, Edmonton, Alberta.

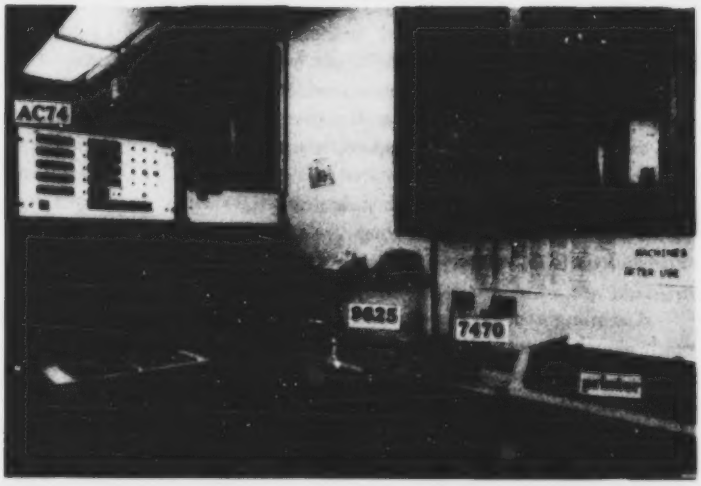

Figure 5. NoFRC Interpretoscope with Altek AC74 3-axis digitizer interfaced to HP 9825 microcomputer with HP 7470 plotter and HP 9871a printer.

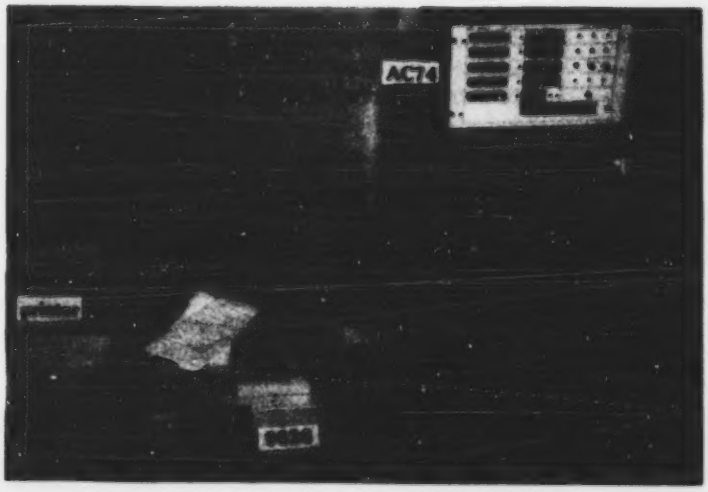

Figure 6. Interpretoscope with Altek AC74 digitizer and more-advanced HP 9826 microcomputer and HP 2631G graphics printer used operationally in the Yukon. Source: B. Bowlby, Forest Resources, Northern Affairs Program, DIAND, Whitehorse, Yukon.

trade-off between the high cost of ground plots and the extra precision to be gained from double sampling. Depending on user objectives, not all steps need to be applied.

The question of stratification is most important because only after sample units are defined can survey methodology be defined. Stratification results in more homogeneous sample units, from which random sampling techniques would yield more precise estimates than would the same number of plots over the same total area without stratification. Stratification should therefore be employed whenever possible when conducting regeneration assessments using large-scale photography. Stratification schemes depend on user objectives, though methods described by Ball and Kolabinski (1979) and Goba et al. (1982) can be used as guides.

Random and systematic plot layout

Simple random sampling (SRS) is where plots are located at random within the area to be sampled (Avery and Burkhart 1983). The main advantages of SRS are that the formulations and computations are simple. Systematic sampling with plots located on a grid layout is easier to implement and simpler to execute then SRS (Cochran 1977), though sampling variation is much more difficult to calculate.

Assuming stocking is of interest, the answer of which sampling method to employ is not always clear, although systematic sampling is generally preferred. Simple random sampling is efficient in terms of numbers of plots, and precise in areas where stocking variation is relatively homogeneous. Assuming plots are uniformly distributed and are therefore representative of the sample area, systematic sampling will generally be more precise than random sampling for the same number of plots. If seedlings are reasonably randomly distributed with respect to the systematic grid layout, however, then systematic sampling can be used with SRS formulas. The survey designer would therefore be able to utilize the advantages of both techniques.

Single- and two-stage designs

Single-stage sampling means that there is only one stage of sampling because no subsampling is involved. For this discussion, single-stage sampling refers to either random or systematic sampling techniques, both of which are more simple to implement than a two-stage design. Two-stage sampling is where whole strips of plots are sampled together, followed by sampling of individual plots from the strips.

Sampling schemes such as simple random sampling or systematic sampling may be employed at each stage. The advantage of two-stage sampling is that it will generally yield estimates of a given precision at a lower cost than that of a completely random sample (Husch et al. 1972). A user's guide for strip sampling and plot location using large-scale photography for estimating stand volume is presented by Macleod (1981). The methodology entails random selection of flight lines (sample strips) across a survey area and random selection of photo plots along these lines. It is often desirable to integrate double sampling (discussed in *Relating photo and ground plots* section) at the second stage. Random selection of sampling units at both stages permits calculation of unbiased estimates of means, standard errors, and sample sizes. Formulations for such are documented in Husch et al. (1972) and Freese (1962).

A user is not limited to use of one sampling technique. The use of several sampling techniques and combinations of them can complicate the selection of a sampling method. In practical terms, the user must relate the survey design to the intended role of the large-scale photography. If the user only wants to conduct a rapid reconnaissance survey to obtain an indication of stocking levels and locations of NSR areas, then average statistics computed from interpretation of all sample plots might be adequate. This approach is typical of many forest surveys where systematic sampling is used with simple random sampling formulas. The user would therefore not need to follow as rigorous a statistical survey design as would be needed if precise estimates were required to within specified accuracy levels. An example of the latter case occurs in Newfoundland, where trials are being conducted with the goal of using LSP to substantially reduce the amount of area requiring intensive ground sampling. Random sampling errors and stocking variability are being calculated for five cutover areas to provide an indication within predetermined levels of accuracy of the sampling intensities required in similarly disturbed areas (Butler 1983).

Plot surveys

A user must decide whether to use single-plot or grouped-plot surveys. Ground surveys often allocate single plots on a systematic or random basis. Due to the cost and method of LSP photo acquisition, the use of group-plot surveys is often advantageous in regeneration assessments. The user should be aware that all plots in a group are sampled because the analysis is done on group means (to calculate the average percent stocking per group for both photo and ground plots), and not on

individual plots. Group-plot surveys are also necessary to enable use of regression techniques for relating photo and ground stocking, because with single plots the stocking is either 0 or 100%. Though a larger number of plots are required in group-plot surveys to achieve the same level of accuracy as in evenly spaced single-plot surveys, fewer group-plot locations are required and therefore total measurement time is reduced.

An important decision to be made in group-plot surveys is the number of plots per group. In regeneration assessments, it should be determined if seedlings occur in clusters. If they do, group sampling is less efficient than if seedlings are more evenly distributed, because all plots in a group tend to give the same information. The optimum number of plots per group can be evaluated statistically by determining the information gained from large and small groups (MacLeod 1982). (An example of this analysis is in the *Effects of plot cluster size and seedling height classes* section discussed later in this report.) If seedlings do occur in groups, then it would be more efficient to have more groups and fewer plots per group.

Relating photo and ground plots

Photo and ground plots are often related using two-phase or double-sampling techniques. Unlike in multi-stage sampling, in double sampling the size of the sample units remains the same (Frayer 1979). Double sampling is often used in large-scale photo sampling because it provides the only means of relating photos to ground samples. This method incorporates a large primary sample (N_p) consisting of photo plots (i.e., each plot is a group of plots). A number of these plots constituting the secondary sample (N_g) are selected for field sampling. Regression techniques are often used to determine the relationship between the samples. The independent variable (X) is photo stocking, and the dependent variable (Y) is ground stocking. Regression is often viewed as a method of calibration for the Np sample (Shuie and John 1962). Photo sampling with a limited ground sample is only more efficient than a straight ground survey if it provides similar information at a reduced cost. If photo plots, however, are not less expensive than ground plots, or if the relationship is poor, then a photo survey is probably not appropriate (Wear et al. 1966).

The following procedure for double sampling with regression is a modification of that presented by Wear et al. (1966):

1. define sample area (e.g., by stratification);
2. determine plot size and shape;
3. define survey design;
4. estimate sample size while considering sample precision;
5. randomly establish plot locations in sample plan;
6. obtain aerial photos;
7. perform photo measurements;
8. field-sample paired plots that have been randomly selected;
9. determine relationship between photo and ground;
10. modify sample size and survey design if necessary; and
11. determine desired parameters.

In practice, more photos are generally acquired than measured. This provides the flexibility for modifying the sample size if necessary.

Formulations leading to the calculation of the variance of the estimated mean (e.g., stocking) are available (Shuie and John 1962; Cochran 1977). The assumptions required that would permit the calculation of sampling error are as follows (Shuie and John 1962):

1. photo plots (N_p) are randomly selected;
2. ground plots (N_g) are randomly selected from the photo plots;
3. measured variables are normally distributed; and
4. linear relationship between photo and ground plots.

In practice, it has been common to use a systematic design with the data being analyzed as a random sample rather than having the samples randomly selected. There is concern in applying double sampling with regression to regeneration assessments for stocking, because there is the possibility of obtaining an estimated ground stocking value that exceeds 100% or is less than 0. In practical application, the simplest solution would be to set ground stocking to 100% if the regression produces a value greater than 100%, or to 0 if it gives a value less than 0. Other techniques, such as the use of a ratio estimate or of conditioned regression,may be used, however, to keep estimated stocking between 0 and 100%. Double sampling with ratio estimate can force the regression line through a designated point. This technique is the preferred approach when the variance of the residuals is not constant (Macleod 1982). Conditioned regression involves restricting the values of the coefficients. An example is setting of the y-intercept to a specified value. The residual sum of squares (RMS) for the conditioned model is always larger than or equal to the RMS of the

unconditioned model (Kozak 1973). The coefficient of determination (R^2) will accordingly be smaller. Of particular importance is ensuring that the data cover the full range of the independent variable. Kozak (1973) suggests that one of three tests should be applied before conditioned regression is used. Due to special conditions that must be observed, conditioned regression should be used with caution with LSP sampling.

Group-plot surveys have been used in regeneration assessments to determine percent stocking in paired photo and ground sampling (double sampling). Larger cluster sizes (e.g., 25 plots/group), however, result in percent values that are more continuous than smaller sizes (e.g., 9 plots/group). The concern then is that smaller group sizes may affect the distribution of the residuals of the regression, causing them to be non-normal[6]. Some care must therefore be taken in determining the number of plots per group.

Sample size of single-stage sampling design

With respect to large-scale photo sampling, the two main aspects of the sample size are the:

1. ratio of photo to ground plots (if double sampling is being employed); and
2. overall sample size.

The total number of plots required in a survey is also governed by the type of survey undertaken. A reconnaissance survey that does not follow a rigid survey design for example, may have as many sample plots as cost and time permit but sampling precision would not be calculable.

The ratio of the number of photo group-plots to ground group-plots (N_p/N_g) can be calculated for either a minimum cost at a given standard error or for a minimum standard error at a given cost (Stellingwerf 1974). A discussion of the formulations and a numerical example for a single-stage random sampling design with double sampling on a subsample are given in Appendix 1. The determination of sample size for two-stage sampling is too complex to be discussed in this report, other than to note that cost and variance are two very important variables (Nichols 1979).

Having some preliminary information concerning the population being sampled facilitates sample size calculations (Macleod 1981). Reliable sample size estimates, however, can be difficult to obtain for LSP surveys even if preliminary information is available concerning sampling variation (Macleod 1979). The best approach is therefore iterative, in which estimates are revised as information is obtained. In addition, estimates should be increased to provide a margin of safety. For example, in forest inventory applications, the ratios of ground to photo plots range from 1:4 to 1:10, depending on cost factors and the relationship between the photo and the ground (Hegyi and Quenet 1982). Applications to regeneration assessments have generally fallen within the same range. In forest stocking the total number of photo and ground groups of plots in group-plot surveys should include measurement of a minimum number of groups of plots on the ground. The greater the variation, the greater the number of group plots that must be surveyed. In practice, consideration must also be given to procuring a ground sample that covers the full range of the independent variable for regression. Previous data and relationships by stratum could be used to assist determination of the total sample. Ground data acquired over several surveys result in a larger number of observations than could be acquired over any one survey. For subsequent surveys in similar areas, only a small ground survey would be necessary. There are several factors (e.g., age of cutover, seedling distribution, site, species) pertaining to the type of stratum being sampled that would govern the feasibility of this approach and whether ground sampling would be necessary for each survey.

RESULTS FROM A RECONNAISSANCE STUDY IN MANITOBA, 1980

A cooperative reconnaissance study was undertaken with Abitibi-Price Inc. in the spring of 1980 in eastern Manitoba to apply large-scale aerial photo sampling to quantifying softwood regeneration on a backlog township (as defined earlier) (93.2 km^2 or 36 sq. mi.). The objectives of the study were to conduct a reconnaissance stocking assessment over the township and to provide an indication of large-scale photo capabilities for regeneration assessments at several scales. Evaluation of capabilities included analysis of conifer detection and species determination percentages, photo and ground plot measurement rates, and identification of

[6] Personal communication by author with D.A. Macleod, Computing and Applied Statistics Directorate, Ottawa, Ontario, June 1982.

shrubs and herbs that may confuse interpretation on the large-scale photos. In addition, the study included brief analyses of the effects of seedling size and cluster plot size using regression statistics from double-sampling data.

Description of study area

The study area is on the extreme southwestern portion of the Northern Coniferous Section (B.22a) of the Boreal Forest Region (Rowe 1972) in southeastern Manitoba. It can be found on the National Topographic System 1:250 000 map sheet 52L (Pointe Du Bois) and is on the southwestern part of the Precambrian Shield. The study area is located immediately south of Oiseau Lake on Township 17 Range 16 east of the Principle Meridian (Fig. 7).

The area is of a complex composition because harvestable softwood stands were progressively clear-cut or selectively cut from 1970 to 1979. Drag scarification using anchor chains was performed on the clear-cut areas of the township from 1973 to 1977. Establishing regeneration consists of predominantly jack pine (*Pinus banksiana* Lamb.) with some scattered spruce (*Picea* spp.) and balsam fir (*Abies balsamea* (L.) Mill.). On selectively cut areas with a hardwood residual, the predominant regenerating softwood understory species were spruce and balsam fir.

Methods

Survey design

The survey design format presented earlier was used as a guide in the Manitoba study. A stratification scheme was needed to place the township into zones that could be interpreted from the large-scale photography. A hierarchical strata classification legend was therefore devised based on interpretation of 1:15 840 black-and-white aerial photographs and Abitibi-Price's inventory map of the study area, using the concept employed by Ball and Kolabinski (1979) (Table 3). All photo plots were interpreted and summarized by stratum.

A single-stage rather than a multistage design was employed due to the reconnaissance nature of the project. No strict adherence to a statistical survey design with random plot selection was therefore considered necessary, and all photo plots acquired were also analyzed. Double-sampling with regression was employed to relate and analyze photo and ground stocking.

Table 3. Hierarchical strata classification legend

Unproductive Forest Land (UFL), i.e., road, water, rock, bog
Productive Forest Land (PFL)
Unlogged (UL)
Logged
Clear-cut (CC)
Stocked hardwoods
Stocked softwoods
Partial cut (PC)
Hardwood residual
Softwood residual

The size of grouped plots (clusters) employed was a square matrix of 5 × 5 (25) subplots or quadrats. The nine quadrats at the center of each 5 × 5 group were evaluated as a separate group to permit a comparison of efficiencies for groups of sizes 9 and 25. The area of each quadrat was 1 millihectare (10 m^2), the same size as is used in Manitoba (Manitoba Department of Natural Resources 1980). The plot cluster of 25 was the largest that could be placed within a stereopair at the photo scale acquired (see photo acquisition section discussed later in the Manitoba reconnaissance study results).

Optimum sample size consideration was given for the ratio of photo to ground plots to provide an indication of how many ground plots were required for the double sample. The number of plots to survey to achieve a specified standard error was not determined. It was difficult to specify a standard error that would be reasonable considering the complexity of the area and the quantity of photography that was to be acquired. Determining the sample size needed to obtain stocking estimates with a specified standard error was also not appropriate due to the number of plots that would be required in relation to the size of the study area (i.e., one township) and the fact that it was a reconnaissance study.

Photo acquisition

The NoFRC camera system with two Vinten cameras was used to obtain photography on April 29, 1980, according to the specifications given in Table 5. One camera with a telephoto lens (281.9 mm) was used to obtain color stereoscopic photos for sampling in groups at fixed intervals along a predetermined flight line

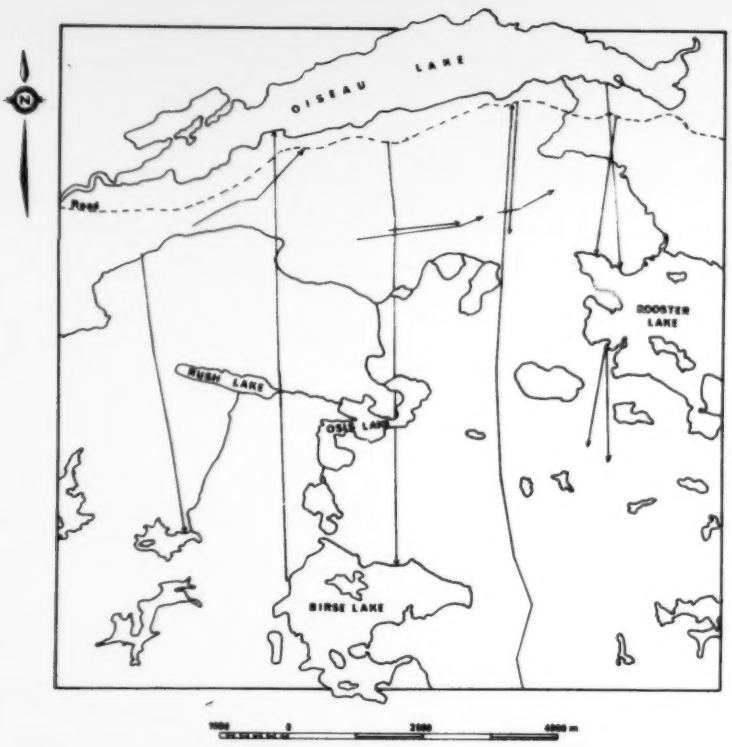

Figure 7. Map of study area showing flight lines.

Table 4. Number of plots

1:580-scale photos			
Total available photo plots (each plot = of 5 × 5 10-m² quadrats)			118
Less no. of plots:			
Productive Forest Land—Unlogged	14		
Unproductive Forest Land	20		
Rejected (obscurity, shadow)	12		
	46		-46
		Total plots	72
1:267-scale photos			
Total available photo plots (each plot = of 3 × 3 10-m² quadrats)			82
Less no. of plots:			
Productive Forest Land—Unlogged	11		
Rejected (obscurity, shadow)	3		
	14		-14
		Total plots	68

and a second camera with a wide-angle lens (77.45 mm) was used to obtain tracking photography. Three scales of large-scale photography using color film were acquired for evaluating their utility for stocking assessments (Table 5). Five north-south flight lines were located approximately 1.6 km apart (Fig. 7). Three of the five flight lines flown at the 150-m altitude were also reflown at the 790-m altitude. An additional four flight lines were flown across the township in short lengths at approximately 75 and 150 m above ground. The objective was to photograph the same areas at different scales.

Measurement-assessment procedure

Flight lines and selected photo plots for ground sampling were located on the 1:15 840 black-and-white photographs. Plots were therefore located on several scales of photography to assist in determining their exact locations. Regeneration assessment was then performed by stratum on both paired and unpaired photo plots. (A paired photo plot is a photo plot that has also been sampled on the ground). The tracking photography was interpreted for strata (Table 3) before the sampling photography was interpreted for stocking. Sampling grids were produced so that upon photo scale determination, a grid could be chosen that would represent the approximate area on the ground. This was accomplished by constructing a grid that was photographed to produce a master negative from which the various grids were made. The grids were produced in representative fraction scale multiples of 1:50 (e.g., 1:400, 1:450, 1:500). The procedure entailed the calculation of photo scale, the selection of the appropriate sampling grid, and its placement onto the photo (see cover photo). Stocking was determined for each group by recording the percentage of quadrats that contained seedlings. Photo interpretation was aided by use of a 4× pocket stereoscope. Grid placement is critical on the plots as the areal location assessed should be the same on the photo and ground. Various features found on the photo that could be located on the ground were used to provide tie points. The photos were subsequently pinpricked once the plot was established. Uniformity and care were also required for grid placement on unpaired photo plots. A systematic unbiased approach was used whereby the grid was placed over the center portion on the left edge of the right photo of the stereopair.

Of the photos acquired, the 1:580-scale photographs were analyzed in the greatest detail because this was the main scale for sampling. Regression statistics were compared to assess the relative efficiency between the 5 × 5 and 3 × 3 cluster plot sizes. The 3 × 3 cluster plot size was placed in the center of the 5 × 5 plots. The same approach was used for the paired plots for all height classes, and height classes greater than 30 cm, to determine the effect of the smaller seedlings on the stocking relationship. Photo and ground plot measurement rates were compared for the 5 × 5 cluster plots in the 1:580-scale photographs. In conjunction with the ground survey, shrubs and herbs that might confuse interpretation on the large-scale photos were identified.

Ground survey

Maps and multiscale photos were used for the selection and location of sample plots on the photos and in the field. Plot corners were pinpricked when photo plots were located on the ground. To determine photo scale more accurately, photo and ground distance measurements were also acquired to develop a regression model for calibrating the radar altimeter (Fig. 8). Field data collection included determination of stocking, tallying and mapping the location of individual trees on each quadrat (Fig. 9), and determining tree species and height. Additionally, information was obtained on the species, location, and areal extent of shrubs and herbs as well as any significant amounts of slash, bedrock, and wet spots. Seedlings tallied were placed into height classes for comparison with their photographic images:

Height class	Height range (cm)
1	<30
2	31-60
3	61-90
4	91-120
5	121-150
6	151 +

Results and discussion

Regression and stocking estimates

Some of the large-scale photographs that were acquired were removed from sampling due to stratum class and poor photo quality. The total number of plots that were evaluated at the two largest scales is given in Table 4.

The optimum allocation formula (Cochran 1977) presented earlier with cost and correlation estimates was used to estimate the 28 groups of plots surveyed. Due to the inherent variation in the data determined from ground sampling, more ground plots would have been desirable but could not be established because of time and cost constraints. Of the 28 ground plots surveyed, 22 were selected from the 1:580-scale and 6 from the 1:267-

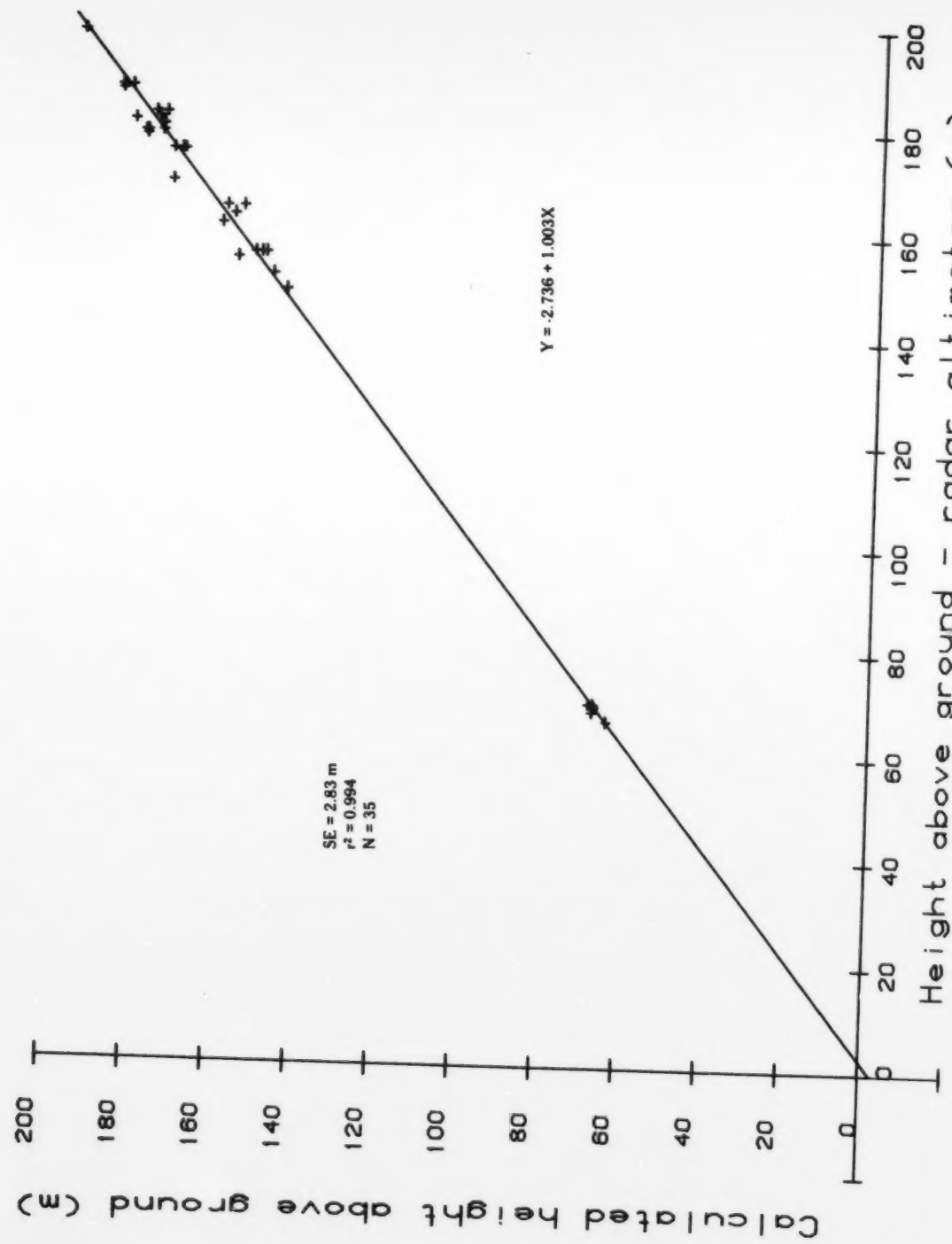

Figure 8. Calibration of radar altimeter.

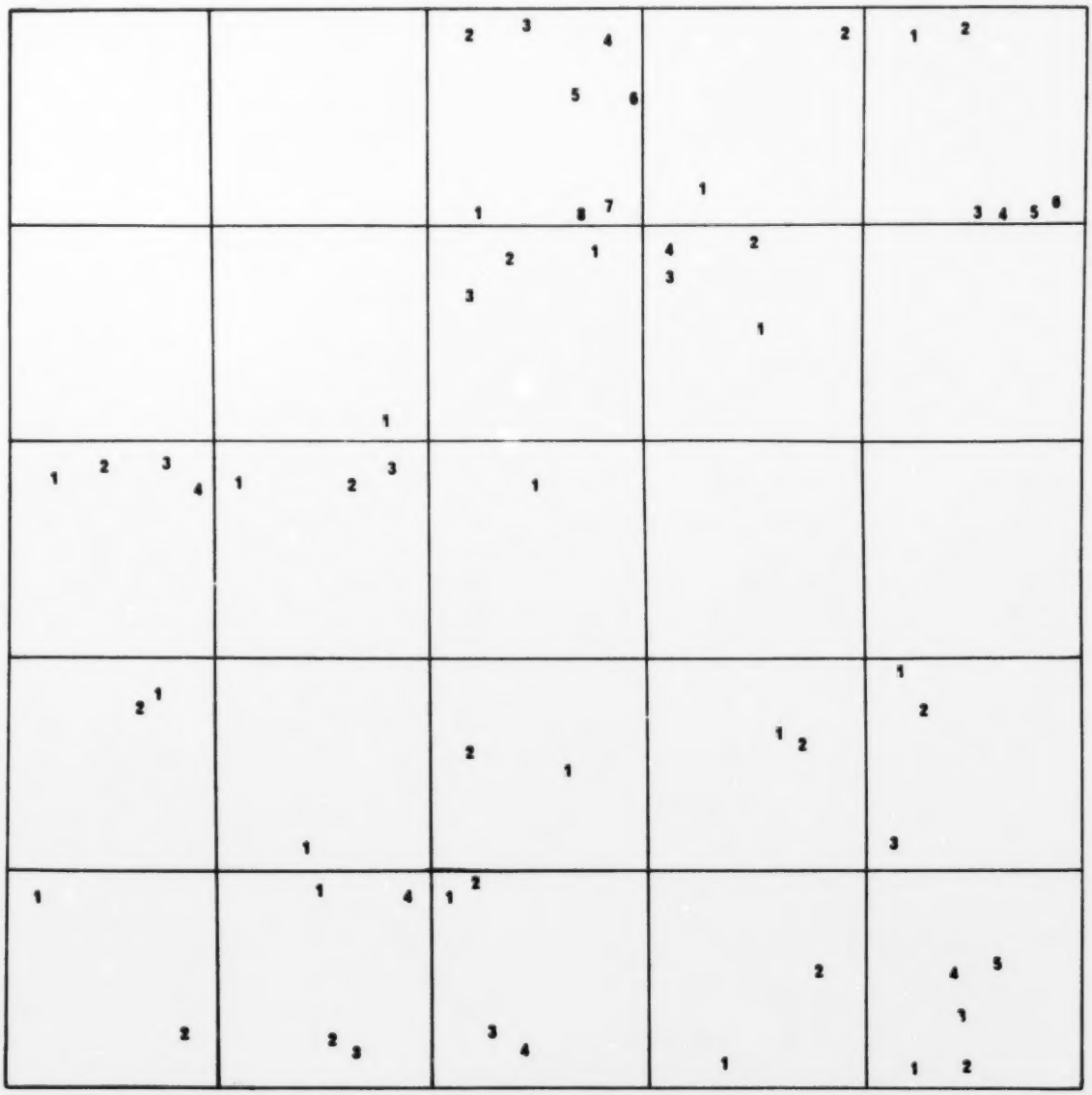

Figure 9. Map of seedling locations in each quadrat of field plot 24 (see cover photo for stereopair of the same plot).

scale photos. The latter group of photos was obtained for comparison purposes with the 1:580-scale photographs. To determine scale more accurately, height-above-ground values were adjusted using the regression equation. The coefficient of determination (R^2) of 0.994 and standard error (SE) of estimate of 2.83 m indicate that the correlation is high and the adjustment is small.

The smallest of the three scales (1:2804) of aerial color photography that were obtained (Table 5) could not be evaluated quantitatively. Due to the small format of the cameras and difficulties in navigation, there was insufficient duplication of the areas where the ground survey was conducted. Emphasis for evaluation was therefore placed on the larger 1:580- and 1:267-scale photos because these provided more-detailed information.

Regression relationships were produced between photo and ground stocking for all height classes and all height classes >30 cm at the 1:580-scale (Table 6 and Fig. 10). The photos at this scale were used to assess the township for stocking. The 1:580 average scale photos fell over four cover types; 58% of all quadrats (1050) occurred in the *Productive Forest Land- Clear-cut stocked to softwoods* stratum (Table 7). The mean corrected stocking using the regression was 51%. The next major stratum class was the *Productive Forest Land—Partial cut hardwood residual*, comprising 30% of all plots. The mean corrected stocking was 44% based on 550 quadrats. Two other stratum classes comprised the balance (Table 7). No correction was applied to the stratum class stocked with hardwoods, because data were not acquired on hardwood regeneration. Little adjustment is required if stocking figures are based on seedlings >30 cm in height (Table 6).

The 1:267 average scale photos only fell over two cover types due to the flight line locations over the townships. The lack of representation of the cover types accounts for the higher stocking values than in the 1:580-scale photos for the same cover types. Fewer plots were sampled because these were measured for comparative analysis. No equation for stocking was produced. A smaller plot cluster had to be used because the larger-scale photos covered a smaller area on the ground.

Stocking for all height classes on the 1:2141-scale CIR photos was compared with stocking on the 1:580-scale color photos. Regression statistics for 21 data points (representing 525 quadrats) were an R^2 of 0.81 and an SE of 9.8%. The regression equation for photo (X) and ground (Y) stocking was $Y = 32.94 + 0.72\ X$. The correlation was still high despite the CIR photos being four times smaller in scale than the color photos. The Y-intercept of 33 means that a ground stocking value of 33% will be obtained with a photo stocking of 0%. Stocking estimates were therefore more conservative than at the 1:580 scale due to the reduced detection of the smaller seedlings. This scale would be useful on older cutovers with relatively tall seedlings, but not for detailed surveys.

A shortcoming of the study was that no information was obtained on where the strata and stocking occurred over the township because no map was produced. How regeneration is distributed is often as important as the quantity of regeneration on an area (Fairweather 1981). The small format of the 70-mm cameras is well-suited for sampling but not for continuous mapping over large areas. The use of a 240-mm format camera (standard 9×9 in. image format) would therefore provide the best means to produce a map showing all strata.

Effects of plot cluster size and seedling height classes

Regression statistics were compared for all height classes, and all height classes >30 cm, for 5×5 and 3×3 plot clusters (Tables 6 and 8). The R^2 and SE are approximately the same for the 5×5 and 3×3 plot clusters at all height classes. Both the intercept and estimator are statistically significant in both equations. The intercept is smaller for the 3×3 plot cluster, which indicates that regression estimates are slightly less conservative for the 3×3 plot cluster than for the 5×5 plot cluster. The mean sum of squares residuals are about the same. If seedlings are clustered, plots on the outside (5×5) are the same as those on the inside (3×3). The larger plot size of 5×5 quadrats is therefore not providing a significantly greater amount of information. It would probably have been more efficient in this study to sample a greater number of smaller plot clusters, though the data would have been less continuous.

There was a large improvement in the estimation of stocking when only seedlings >30 cm in height were considered (Table 6). The equation was much less conservative since there was a reduction in the intercept from 24.278 to 5.600. There was an improvement in the R^2 from 0.873 to 0.961 and a reduction in the SE of 2.664. The regression therefore accounts for a greater amount of the total variation than when all height classes were considered. This accounts for the corresponding reduction in the significance level of the intercept. These results imply that stocking was influenced by seedlings <30 cm in height, raising the question of the importance

Table 5. Flight specifications

	Average scale					
	1:267	1:972	1:580	1:2141	1:2804	1:10207
Flying height (nominal) (m)	75	75	150	150	790	790
Focal length (mm)	281.9	77.45	281.9	77.45	281.9	77.45
Overlap (nominal) (%)	70	60	70	60	70	70
No. frames/group	4	1	3	1	1	1
Distance between group (nominal) (m)	160		270			
Shutter speed (s)	1/2000	1/1000	1/2000	1/1000	1/1000	1/1000
Film (c = color, CIR = color infrared)	C	CIR	C	CIR	C	CIR

Table 6. Double sampling with regression statistics, 5 × 5 plot cluster

5 × 5 plot cluster, all height classes at a scale of 1:580

Equation: $Y = 24.978 + 0.752\ X$
X = photo stocking (%)
Y = ground stocking (%)
Coefficient of determination (R^2) = 0.873
Standard error of estimate (SE) = 8.215
T-value and significance level of estimator: 11.714, 0.000
T-value and significance level of intercept: 6.312, 0.000

Analysis of variance

	DF[a]	Sum of squares	Mean square	F
Regression	1	9259.705	9259.705	137.206
Residual	20	1349.750	67.487	

5 × 5 plot cluster, all height classes >30 cm at a scale of 1:580

Equation: $Y = 5.600 + 0.964\ X$
$R^2 = 0.961$
SE = 5.551
T-value and significance of estimator: 22.229, 0.000
T-value and significance of intercept: 2.094, 0.049

Analysis of variance

	DF[a]	Sum of squares	Mean square	F
Regression	1	15229.403	15229.403	494.128
Residual	20	616.415	30.821	

[a] Degrees of freedom.

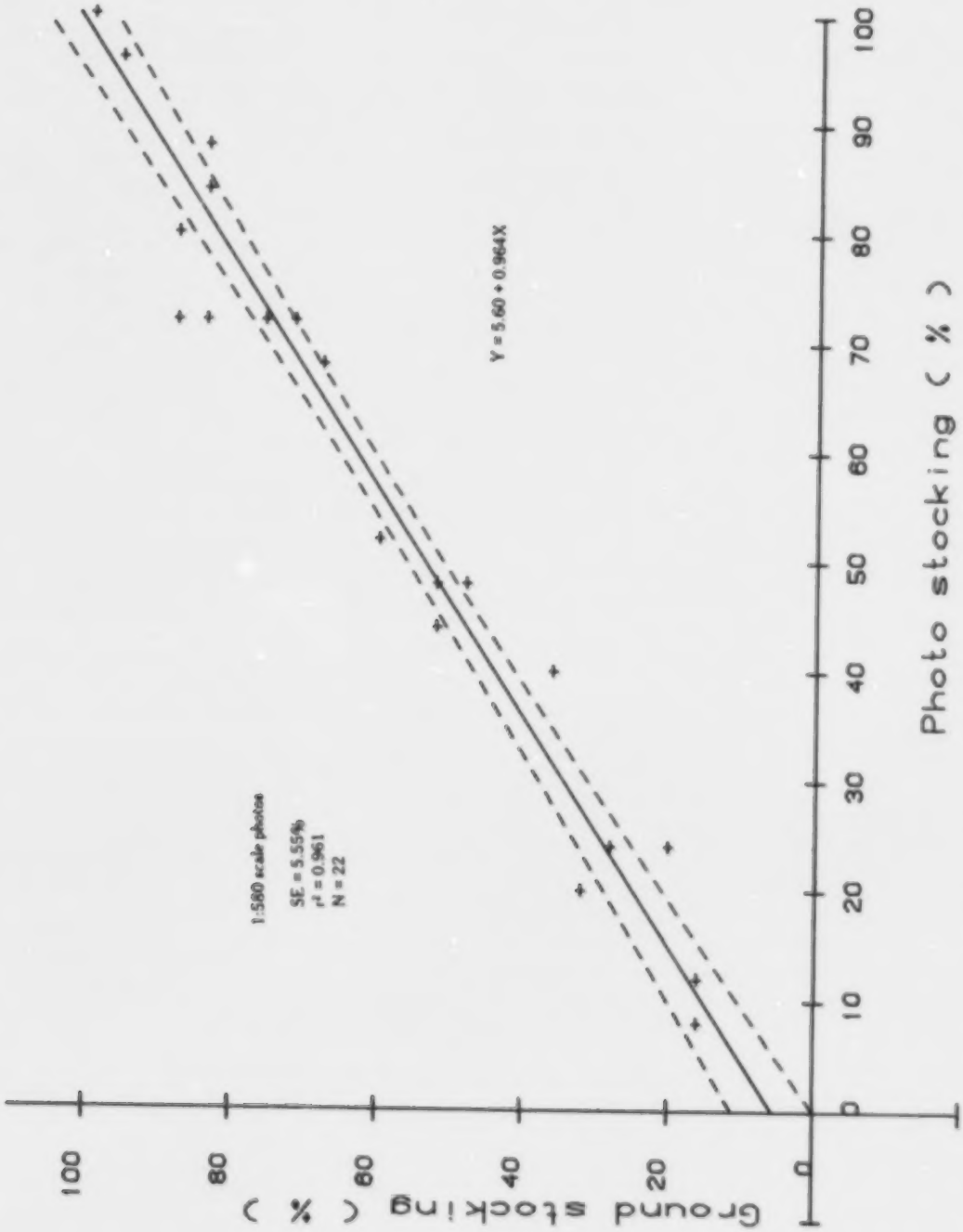

Figure 10. Regression plot for 5 × 5 plot cluster and all height classes >30 cm.

Table 7. Regeneration stocking figures obtained from the reconnaissance survey

Stratum	Average scale	No. of plots	Total no. of quadrats (10 m²)	Average photo stocking (%)	Corrected average photo stocking (%)	
					All height classes	Height classes >30 cm
1:580-scale photos (5 × 5 quadrats)						
Productive Forest Land—partial cut hardwood residual	1:597	22	550	40	55	44
Productive Forest Land—clear-cut stocked softwoods	1:576	42	1050	47	60	51
Productive Forest Land—clear-cut stocked hardwoods	1:600	1	25	44		
Productive Forest Land—partial cut softwood residual	1:591	7	175	48	61	52
Total		72	1800			
1:267-scale photos (3 × 3 quadrats)						
Productive Forest Land—partial Cut hardwood residual	1:301	12	108	59		
Productive Forest Land—clear-cut stocked softwoods	1:260	56	504	68		
Total		68	612			

Table 8. Double sampling with regression statistics, 3 × 3 plot cluster

3 × 3 plot cluster, all height classes at a scale of 1:580

Equation: $Y = 19.475 + 0.827\ X$
X = photo stocking (%)
Y = ground stocking (%)
Coefficient of determination (R^2) = 0.887
Standard error of estimate (SE) = 7.953
T-value and significance level of estimator: 12.558, 0.000
T-value and significance level of intercept: 4.590, 0.000

Analysis of variance

	DF[a]	Sum of squares	Mean square	F
Regression	1	9975.745	9975.745	157.716
Residual	20	1265.028	63.251	

3 × 3 plot cluster, all height classes >30 cm at a scale of 1:580

Equation: $Y = -3.025 + 1.051\ X$
$R^2 = 0.891$
SE = 9.914
T-value and significance of estimator: 12.803, 0.000
T-value and significance of intercept: -0.572, 0.574

Analysis of variance

	DF[a]	Sum of squares	Mean square	F
Regression	1	16111.229	16111.229	163.921
Residual	20	1965.725	98.286	

[a] Degrees of freedom.

Table 5. Percent conifer detection and species determination by height class

Height class	Conifer detection		Species determination	
	%	No. of trees	%	No. of trees
	1:580-scale photos			
1. <30 cm	8	155	0	19
2. 31-60 cm	77	176	10	31
3. 61-90 cm	96	179	47	49
4. 91-120 cm	100	102	90	39
5. 121-150 cm	100	73	100	33
6. 151+ cm	100	77	100	36
	1:267-scale photos			
1. <30 cm	57	7	0	3
2. 31-60 cm	89	18	35	17
3. 61-90 cm	95	20	53	15
4. 91-120 cm	100	14	75	8
5. 121-150 cm	100	22	100	18
6. 151+ cm	100	29	100	29

of very small seedlings in reconnaissance studies. Because reconnaissance studies, particularly for backlog areas, are intended only to provide an indication of regeneration status in older disturbed areas, it might not be worthwhile to consider these smaller seedlings.

Similar results, though not as large in magnitude, occurred for the 3 × 3 plot clusters when only seedlings >30 cm were considered (Table 8). The intercept is only significant at the 57% level, which indicates that only the regression estimator is really needed. The use of 3 × 3 plot clusters results in stocking estimates that are less continuous than those for 5 × 5 plot clusters. The cruder estimates would explain the increase in the SE from 7.9 to 9.9%. Stocking estimates will not be equal on a per-plot basis, though they should be reasonable on the average.

Conifer detection and species determination

Ground and photo data were compared to provide an indication of the differences between the two largest scales for conifer detection and species determination by height class (Table 9). Detection was low (8%) at Height Class 1 for trees less than 30 cm tall on the 1:580-scale photos. The larger-scale photos were better for detecting smaller seedlings. The detection percentages were essentially the same from Height Class 3 and up. The larger photo scale made a difference for only those trees in Height Class 2 and smaller. The significance of these figures depends on what information is really needed. For example, detection of three of five seedlings on a quadrat would not be serious in quantifying stocking on the basis of height because only one seedling is required for a quadrat to be considered stocked.

Only a few trees per group-plot were identified and used to determine species. Low species determination percentages for trees up to Height Class 3 were obtained for both large-scale photos (Table 9). The 1:267-scale photos were easier to interpret and higher determination percentages resulted. Although some confusion did occur between spruce and balsam fir, it was much more prominent on the smaller seedlings. No differentiation was made between white spruce (*Picea glauca* (Moench) Voss) and black spruce (*Picea mariana* (Mill.) B.S.P.). The Manitoba regeneration survey method considers both white and black spruce to be acceptable regeneration species (Manitoba Department of Natural Resources 1980) and therefore differentiation is not necessary. An increased base-to-height ratio, obtained with a 150-mm lens instead of a 280-mm lens, would likely have improved the study results because of the increased vertical exaggeration.

Confusion in interpretation

The species of ground vegetation that could cause some confusion when interpreting large-scale photos for forest stocking were identified (Table 10). Each shrub and herb has particular characteristics, however, that enable a trained interpreter to make the distinction. Other major impairments to the assessment of stocking were overstory vegetation, shadows, wood residues, and clumps.

Table 10. Possible sources of confusion in interpretation—shrubs and herbs

Juniper	— *Juniper communis* L. or *J. horizontalis* Moench (shrub)
Labrador tea	— *Ledum groenlandicum* Oeder (shrub)
Club moss	— *Lycopodium* spp. (herb)
Bearberry	— *Arctostaphylos uva-ursi* (L.) Spreng. (dwarf shrub)
Balsam layering	— *Abies balsamea* (L.) Mill.

Other results

The 1:10 207-scale CIR photos are useful for areal stratification of regeneration into somewhat homogeneous areas. Complete coverage, however, is not possible unless scales of 1:30 000 or smaller are obtained. A map of the entire sample area is best produced from a larger-format camera. An optical instrument could then be used to transfer photo-delineated boundaries onto a base map.

Measurement production rates were estimated to obtain an indication of differences between photo and ground. At the 1:580 scale, an average of four plots per hour (or 100 quadrats per hour) was obtained. Approximately three plots per day (75 quadrats) were attainable with a two-man crew in the field. Photo sampling rates are therefore faster than ground sampling rates for the same size of plot. This gain in efficiency would be much more pronounced in remote areas where access is difficult. The use of a more sophisticated measurement-interpretation system utilizing a microcomputer, printer, and plotter will improve data processing (such as sorting and summarizing stocking information) and assist production of more information (such as producing a map of seedling locations), but will reduce photo plot measurement rates accordingly.

An attempt was made to discern possible reasons for low stocking on some plots by estimating percent coverage of rock or slash using a 64 dot/sq. in. grid. Virtually no correlation was obtained, however, to attribute low stocking to high percentages of rock outcrop or slash.

SUMMARY

Greater awareness of the considerations for use of large-scale photography in regeneration assessments will assist the potential user to make more knowledgeable decisions. Once the survey objectives have been determined, the user must decide whether to acquire the photography under contract. Continual use of large-scale photography in an operational program will warrant consideration for purchase of a camera system. The flow chart concept is suggested as a base on which to develop a flow of procedures for varying applications of large-scale aerial photography due to the inherent flexibility that exists.

Considerable controversy has developed over which camera system configuration to employ. This question cannot be answered easily and requires consideration of system availability and the range of intended applications. The information provided in this report is not intended to be all-inclusive. Rather, the report documents some of the technical characteristics of the camera systems. Most importantly, the economic feasibility of large-scale photo acquisition is governed by the total size of the sampling area, the survey design, the cost of the aircraft rental, the ferry cost of the aircraft to fly to the sample area, and the cost of the contractor, if applicable.

Measurement-interpretation systems can range from a pocket stereoscope with grids and a calculator, to the use of microcomputers interfaced with stereoviewing equipment. The latter provides more capability and data processing power but will reduce photo measurement rates.

The user is not necessarily limited to the sampling techniques that are most often employed, though the survey design format presented in this report is general and applicable to most situations. The number of plots per group should be determined from field sampling and should depend on the degree of clustering of the seedlings. Futhermore, regardless of the methods used in determining sample sizes in double sampling, the number of ground plots must be large enough to account for the range of conditions in each stratum.

Photography for the cooperative reconnaissance project with Abitibi-Price Inc. was flown in the spring when sun angles are high and the opportunity exists for fieldwork during the summer. A high correlation was calculated between photo and ground stocking at the three scales evaluated. The smaller the photo scale, the more conservative the stocking estimates due to the increase in generalization. Stocking estimates were obtained by stratum using the average 1:580 scale photography. At scales of approximately 1:600 and larger, large-scale photography can be used to accurately assess regeneration of 30 cm in height and greater. Species interpretation of trees 90 cm in height and taller is possible with better than 90% accuracy. An interpreter must learn to distinguish regeneration from shrubs and herbs. A preliminary field trip should be made to obtain data for comparing the mean square residual statistic to aid determination of the optimum cluster size for plots. Double-sampling regression statistics and sample size calculations could be done, and would provide the necessary data to determine if a second field trip would be necessary. Data from previous surveys on similar areas would provide the most economical approach for a company or agency employing these methods in an operational program.

The measurement production rates presented in this report should provide an indication of the potential economical efficiency in using photo plots in comparison to ground plots. The figures presented on capabilities are intended to be indicative of large-scale photo capabilities and not necessarily the best attainable. The use of more sophisticated instrumentation (e.g., Interpretoscope, Stereocord) and a wider-angle lens (such as a 150-mm lens) to improve the base-to-height ratio would consequently improve height detection and species determination percentages. A more complete survey could have been done by producing a stratification map indicating where different strata and stocking densities occurred over the township.

This report summarizes the capabilities of and considerations for use of large-scale photography for regeneration assessments. The tools, potential, and means to provide detailed, permanent record data for efficient assessments are now available for implementation by the forest manager.

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APPENDIX 1

DETERMINING SAMPLE SIZE

The following discussion is for a single-stage random sampling design with double sampling on a subsample. Sample size calculations often evolve around the following general cost function:

$$C_T = C_p N_p + C_g N_g \qquad (1)$$

where: C_T = total cost
C_p = cost of one photo plot
C_g = cost of one ground plot

For purposes of discussion, one plot will refer to one group of plots (group-plot). Several approaches can be used to calculate sample sizes in double sampling, though the most frequently used approach is to apply the optimum plot allocation with respect to cost formula presented by Cochran[1], Stellingwerf[2], and Shuie and John[3]:

$$\alpha = \frac{\text{no. of photo plots } (N_p)}{\text{no. of ground plots } (N_g)} = \left[\frac{r^2}{1 - r^2} \bullet \frac{C_g}{C_p}\right]^{1/2} \qquad (2)$$

where α = ratio of N_p/N_g
α = correlation between photo and ground plots

A preliminary survey is needed to give estimates of variables for formula (2). Once ground survey is completed and the relationship determined using regression, the optimum ratio can be recalculated.

In group-plot surveys for stocking, a single percent stocking figure is obtained for each group-plot. Therefore, when groups of plots are used instead of single plots, parameters C_p, C_g, C_t, N_p, N_g, and s^2 apply to groups rather than single plots. Once the ratio of N_p to N_g is otained, there are two methods of estimating N_p and N_g. For the first method, since the group-plots are randomly located, the sample size formula for simple random sampling is applicable if the objective is to estimate stocking to within specified error limits:

$$N_p \text{ or } N_g = \frac{t^2 s^2}{E^2} \qquad (3)$$

where: s^2 = sample variance of either ground or photo plots depending on which is being calculated.

$E = \pm$ error of sample mean desired

The above formula is an approximation and usable under the condition that the number of plots being calculated must not be too small. The number of plots used in the double sampling with regression must be representative and large enough to account for the variation over the survey area, and must cover the entire range over which the regression is intended to be applied. Assuming uniform variance, the preliminary sample may be from either the photo or ground, though a ground survey would be preferable due to the relative accuracy of the sample mean. The appropriate variance term must be used depending on whether the preliminary sample was from the photo or ground. The N_p or N_g can then be used with the optimum ratio to calculate the number of plots required. The final step is to determine total cost by use of the cost function.

The second method would preclude consideration of sampling precision by combining the optimum ratio with the cost function to calculate the number of plots using

$$N_p = \alpha N_g \qquad \text{from (2)}$$

therefore; for a fixed cost C_T, the number of ground plots is determined by

$$N_g = \frac{C_T}{C_g + C_p \alpha} \qquad (4)$$

Another method similar in some aspects to the above but which employs costs, standard errors, and a graph for efficiency, is given by Wear et al.[4]

A hypothetical numerical example

Large-scale photos were acquired over a backlog area that has been harvested and is now regenerating

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[1] Cochran, W.G. 1977. Sampling techniques. 3rd ed. John Wiley and Sons. Rexdale, Ont.

[2] Stellingwerf, D.A. 1974. Optimum ratio of photo-field plots for aerial volume and aerial volume growth regression construction. Pages 323-335 *in* G. Hildebrandt, editor. Proc. XVI IUFRO World Congress, Oslo, Norway.

[3] Shuie, C.; John, H.H. 1962. A proposed sampling design for extensive forest inventory: double systematic sampling for regression with multiple random starts. J. For. 60(9):607-610.

[4] Wear, J.F.; Pope, R.B.; Orr, P.W. 1966. Aerial photographic techniques for estimating damage by insects in western forests. USDA For. Serv., Pac. Northwest For. Range Exp. Stn.

with softwoods. A single-stage random sampling design was used with double sampling. How many photo and ground plots are required to estimate stocking to within 20% of the true mean, and what will be the total cost?

Double sampling is performed using 22 paired photo and ground plots. Assume that one plot is one group of 25 millihectare plots (quadrats).

Regression statistics:

Ground stocking (%) = 5.600 + 0.964 photo stocking (%)

R^2 = 0.961 error mean square = 30.821
S^2_g = 754.54 mean ground stocking = 58.9%

Cost of one ground plot (C_g)
= \$80.00 (\$3.20/millihectare plot)

Cost of one photo plot (C_p)
= \$20.00 (\$0.80/millihectare plot)

Recall that the sample for the regression should be representative of the sample area and cover the entire range of the regression.

1. Use equation 2 to determine the optimum ratio:

$$\alpha = \frac{N_p}{N_g} = \left[\frac{r^2}{1 - r^2} \bullet \frac{C_g}{C_p}\right]^{1/2}$$

$$= \left[\frac{0.9610}{1 - 0.961} \bullet \frac{0.80}{20}\right]^{1/2} = \frac{9.9}{1} \cong \frac{10}{1}$$

2. Calculate the number of ground plots that would be required:

T-value at 95% probability level for 21 degrees of freedom = 2.08

$$Ng = \frac{t^2 s^2_g}{E^2} = \frac{2.08^2\,(754.54)}{[0.20\ (58.9)]^2} = 23.5 \text{ plots}$$

Therefore, 24 ground plots are required.

Assuming that the ground sample was representative of the sample area, the size of the double sample was not adequate and more field sampling is needed.

3. Calculate the number of photo plots required for the optimum allocation:

$$N_p = N_g \alpha = 24\ (10) = 240 \text{ photo plots}$$

4. The total cost of the project using the cost function is:

$$C_T = C_p N_p + C_g N_g$$
$$= \$20.00\ (240) + \$0.80\ (24)$$
$$= \$6720.00$$

which is the total cost for 6000 millihectare photo quadrats and 600 millihectare ground quadrats.

Recall that 22 ground plots were surveyed during the double sample. In practical application, the number of ground plots actually surveyed would be used, assuming that it is equal to or greater than the number of ground plots required to meet the desired accuracy.

The total cost expressed on a per-hectare basis is dependent on many factors, including the total area being surveyed, the stocking variability, and access. Generally, the larger the area being assessed, the greater accessibility and the more uniform the stocking variability, the lower the cost on a per-hectare basis.